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TITLE: RESONATOR OPTICAL DESIGNS FOR FREE ELECTRON LASERS

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Resonator Optical Designs for Free Electron Lasers

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Abstract

The output beam from free-electron lasers tends to be a thin, pencil-like beam because of the nature of the gain volume. For moderate power devices, mirror damage considerations imply that the beam has to travel many meters before it can expand enough to allow retro-reflection from state-of-the-art mirrors. However, use of grazing incidence optics can resolve the problem of damage to the optical elements and result in a cavity of reasonable dimensions. The optical design considerations for such resonators are addressed in this paper. A few of the practical resonator designs approaching diffraction limited performance are presented.

Introduction

The gain medium for free-electron lasers is usually a volume that is close to an on-axis region that is thin and pencil like. This results in a cavity length that is many meters long to avoid damage to optical elements in the cavity, even if state-of-the-art mirrors are used. In addition to the length of the cavity, attendant problems of alignment sensitivity, thermal and mechanical stability of the cavity make cavities of such lengths difficult to operate.

Near normal incidence reflectors and refractors have to be ruled out on the basis of mirror damage considerations alone.

Because of these difficulties, we looked into the use of cavities with all reflecting elements. In addition, the use of grazing incidence optics would help a lot in solving the damage problems to the optical elements. Grazing incidence optics have been successfully used in x-ray and EUV astronomy[1-3] for imaging applications. P. B. Mumola and D. C. Jordan[4] have proposed the use of such optics to focus the beams in lasers used in fusion. They have shown that the use of grazing incidence optics to avoid damage to optical elements has several advantages. Specifically, the Fresnel equations indicate that metal mirrors used at high angles off incidence result in reduced absorption of properly polarized light, resulting in a commensurate improvement in damage resistance. Also, for a given mirror figure error, lower transmission losses and improved wavefront quality result. We have extended this approach to study the design of resonators for the free-electron laser.

Optical designs for various candidate resonators for the free-electron laser

The major requirements for the resonator cavity for free-electron lasers include, among other criteria, the following requirements: 1) use of elements that can withstand damage to elements, 2) optical elements that can be successfully manufactured within the framework of current technology, 3) an output beam which is sufficiently large (~25 cm diameter) so that conventional optical elements can be used at the output of the resonator, and 4) a nearly diffraction limited output (<λ/10 peak to valley in terms of wavefront quality).

The various candidate systems designed to meet these requirements are shown in Figure 1. The typical optical element combinations are: 1) hyperboloid-paraboloid, 2) hyperbola-parabola, and 3) cylinder-cylinder. Table 1 gives details of the constructional parameters for the systems. Table 2 gives details of tolerances typical of these systems when used as resonators. We are showing only one half of the cavity in Figure 1. The other half of the cavity is identical to the half shown in Figure 1 and Table 1. The cylinder-cylinder has potentially the highest aberration and the hyperbola-parabola is a difficult fabrication problem. These two cases are also not rotationally symmetric. However, the hyperboloid-paraboloid case is aberration free at any F number and has the advantages of a rotationally symmetric system. We chose this system for further refinements in design and an optimized low expansion glass version of this design is being manufactured by the Perkin-Elmer Corporation at the present time.[6,7] The two papers referred to in References 6 and 7 are being presented at this conference also. We give details on the design as well as the manufacture of this system. Table 3 gives details of the hyperboloid-paraboloid resonator system with a half cavity length of 23.4 meters on which the system currently being manufactured is based. The work described in this paper was done using ACCOS V.[7] As most of the analysis done using ACCOS V was based heavily on geometric considerations, further refinements are needed to account for the physical optics problems that have to be addressed in the final resonator design. This is also pointed out in the papers referred to in Reference 7.

We limited our search to solutions which can be used as either a near concentric resonator or a ring resonator. Figure 2 shows the schematic of a near concentric resonator. All the designs have been basically derived from the Wolter[5] configurations, and modified for the purpose of making them functional as resonator cavities. Our idea was to extend the Wolter concept to cases where the grazing incidence optics results in a magnifier with a large (~25 cm diameter) beam as the output beam which is collimated (for the ring resonator) or nearly collimated (for the near concentric resonator).

Summary and conclusion

The use of grazing incidence optics (for the first element of the resonator) for free electron laser resonators appears to be a good solution to a difficult problem. The basic hyperboloid-paraboloid solution has been optimized, and is currently being manufactured by the Perkin-Elmer Corporation.[6] We hope to set up the cavity design described in the those papers[7] at Los Alamos and study the properties of such a resonator. We believe that this is the first time a resonator cavity with grazing incidence optics has been tried. The results should prove interesting and provide good insights for the validity of current resonator analysis programs and help us understand the grazing incidence resonator properties.

References

1. J. H. Underwood, "X-ray Optics," American Scientist, Vol. 66, p. 476, 1978.
2. "Space Optics: Imaging X-ray Optics Workshop," __ SPIE Proc., Vol. 184, 1979.
3. "X-ray Imaging," SPIE Proc., Vol. 106, 1977.
4. P. B. Mumola and D. C. Jordan, "Glancing Incidence Optics for High Power Lasers," SPIE Proc. of Los Alamos Conference on Optics '81, Vol. 288, pp. 54-62.
5. H. Wolter, "Glancing Incidence Reflecting Systems for Optical Imaging by X-ray," Annuals of Physics, Vol. 10, No. 1, 2, pp 94, 1952.
6. Andrea Sarnik and Paul Glenn, "Optical Design Considerations for Grazing Incidence Elements in a Free Electron Laser," Southwest Conference on Optics '85.
7. P. R. Akkapeddi, P. Glenn, A Fuschett, G. Appert, and V. K. Viswanathan, "Grazing Incidence Beam Expander," Southwest Conference on Optics '85.
8. ACCOS V is a proprietary optical design code from Scientific Calculations, Inc. Fishers, NY 14453.

Table 1. Construction Parameters for Various Systems

Half Cavity Length (m)	Size (cm) Y x X	Area (cm^2)	Radius (cm)	Size (cm) Y x X	Area (cm^2)	Radius (cm)
			Hyperboloid/Paraboloid Configuration 25 cm Diameter Output Beam			
28.5	67.4 x 8.0	423.0	5.06	316.1 x 42.1	10,451	30.0
23.4	72.9 x 6.5	375.6	2.11	350 x 33.0	9,621	12.5
18.9	44.9 x 5.3	187.0	3.38	263.4 x 35.1	7,261	25.C
			Cylinder/Cylinder Configuration 25 cm Diameter Output			
34	260 x 24	4,944	2152	272 x 25	5,347	-040.3
			Hyperbola/Parabola Configuration 25 cm Diameter Output			
34	259 x 24	4,882	3278.4	272 x 25	5,341	-752.8

Half Cavity Length (m)	Displacements Between Last Two Elements Δ Y (m)	Δ Z (m)	Angle of Inc. θ Mirror 1	θ Mirror 2
		Hyperboloid/Paraboloid Configuration 25 cm Diameter Output Beam		
28.5	2.6	13.3	85.2°	84.6°
23.4	1.4	9.9	86.3°	85.9°
18.9	2.2	11.6	85.2	84.6
		Cylinder/Cylinder Configuration 25 cm Diameter Output		
34	.277	1.576	85°	85°
		Hyperbola/Parabola Configuration 25 cm Diameter Output		
34	.296	1.7	85°	85°

Table 2. Resonator Tolerance Study
Alignment Tolerance to Centerline with Effective Zero OPD

.0005° Decollimation

Case	Cavity Length	Cavity Tolerance (mm)	Radius 1(mm)
Hyperboloid/Paraboloid	70 m	±.70	±.075
Cylinder/Cylinder	50 m	+33.0, -31.5	+.075, -.072
Cylinder/Cylinder	70 m	+64.8, -62.0	+.145, -.140
Hyperbola/Parabola	50 m	+33.0, -32.5	+.001, -.008
		.00005° Decollimation	
Hyperboloid/Paraboloid	70 m	+.70	±.0075
Cylinder/Cylinder	50 m	+4, -2.5	+.009, -.006
Cylinder/Cylinder	70 m	+7.8, -5.0	+.012, -.017
Hyperbola, Parabola	50 m	+3.4, -3.2	+.0086, -.008

Table 2. (continued)

Case	Cavity Length	Beam Displacements at Mirror No. 1 YD 1 (mm)	XD 1 (mm)	Radius 2(mm)	Beam Displacements at Mirror No. 2 YD 2 (mm)	XD 2 (mm)
		.0005° Decollimation				
Hyperboloid/Paraboloid	70 m	±1.1	±1.1	±1.2	±.095	±.09
Cylinder/Cylinder	50 m	±2.55	±.02	+.093, -.097	±.255	±.023
Cylinder/Cylinder	70 m	±.36	±.031	+.176, -.184	+.091, -.066	±.035
Hyperbola/Parabola	50 m	±.255	±.02	+.105, -.104	±.255	±.023
		.00005° Decollimation				
Hyperboloid/Paraboloid	70 m	±.11	±.11	±.12	±.0095	±.009
Cylinder/Cylinder	50 m	±.0255	±.0019	+.008, -.011	±.0255	±.0022
Cylinder/Cylinder	70 m	±.0355	±.0025	+.022, -.014	±.0355	±.0028
Hyperbola/Parabola	50 m	±.0255	±.002	+.01, -.011	±.0256	±.0023

Table 3. Details of Hyperboloid/Paraboloid System

FEL Front Hyp. (23.4M 1/2 Cavity 7-18-83)

Basic Lens Data

Surf	RD	TH	Medium	RN	DF
0	0.000000	.312500E+05	Air		
1	0.000000	-.187500E+05	Air		
2	0.000000	8625.000000	Air		
3	21.114448	10.551949	FEFL		
4	0.000000	9375.000000	Air		
5	0.000000	-9375.000000	Air		
6	0.000000	0.000000	Air		
7	0.000000	-62.500000	Air		
8	125.000000	0.000000	FEFL		
9	0.000000	625.000000	Air		
10	0.000000	.312500E+05	Air		
11	0.000000	625.000000	Air		
12	0.000000	0.000000	Air		

CC and Aspheric Data

Surf	CC	AD	AE	AF	AG
3	-.10020E+01				
8	-.10000E+01				

Tilt and DEC Data

Surf	Type	Yd	XD	Alpha	Beta	Gamma
3	Tilt	0.00000	0.00000	0.0000	0.0000	0.0000
6	Tilt	0.00000	0.00000	0.0000	0.0000	0.0000

Ref Ojb HT		Ref AP HT	OBJ Surf	Ref Surf	Img Surf
.125000E-01	(-.00 DG)	1.25000	0	1	12

EFL	BF	F/NBR	Length	OID	T-Mag
125085.0063	625.0000	*********	40448.0519	53573.0519	-18530.270111

Wavl Nbr	1	2	3	4	5
Wavelength	.58756	.48613	.65627	.43584	.70652
Spectral Wt	1.0000	1.0000	1.0000	1.0000	1.0000

No Aperture Stop
Lens Units Are MM
Evaluation Mode is afocal
Control Wavelength is 1
Primary Chromatic Wavelengths are 2 - 3
Secondary Chromatic Wavelengths are 2 - 1

FIGURE 1
GRAZING INCIDENCE ANGLE FEL CAVITY CONFIGURATIONS

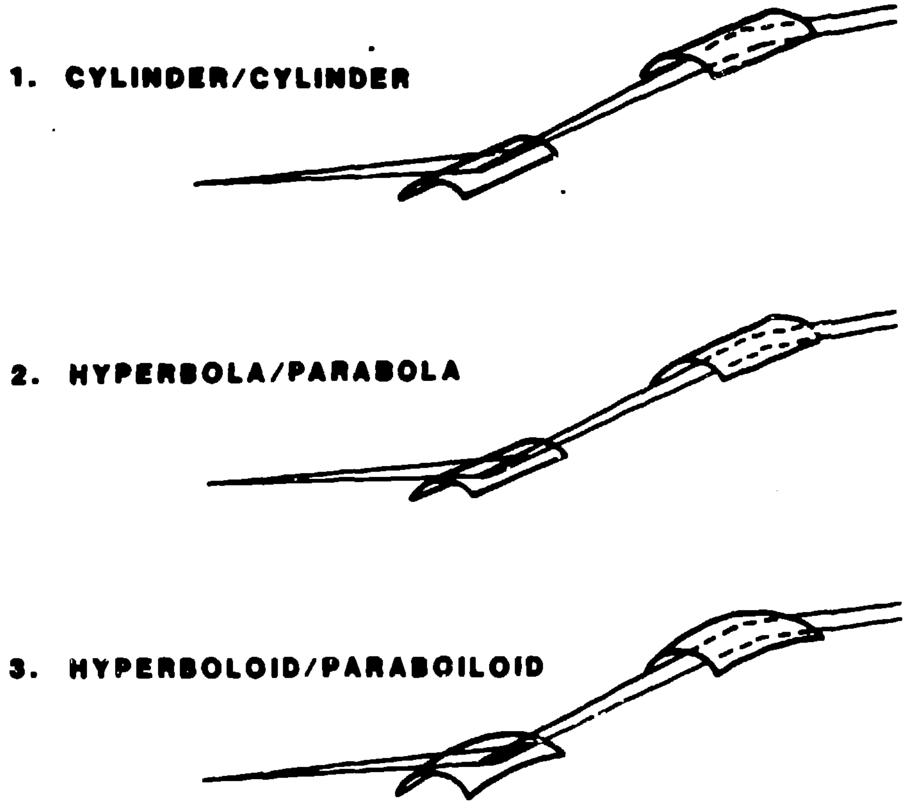

FIGURE 2
NEAR CONCENTRIC RESONATOR